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Single-aging characteristics of 7055 aluminum alloy

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Abstract: The microstructures and properties of 7055 aluminum alloy were studied at different single-aging for up to 48 h using hardness test, tensile test, electrical conductivity measurement, XRD and TEM microstructure analysis. The results show that at the early stage of aging, the hardness and strength of the alloy increase rapidly, the peak hardness and strength are approached after 120 ℃ aging for 4 h, then maintained at a high level for a long time. The suitable single-aging treatment of 7055 alloy is 480 ℃, 1 h solution treatment and water quenching, then aging at 120 ℃ for 24 h. Under those condition, the tensile strength, yield strength, elongation and electrical conductivity of the studied alloy are 513 MPa, 462 MPa, 9.5% and 29%(IACS), respectively. During aging, the solid solution decomposes and precipitation occurs. At the early aging stage of 120 ℃, GP zones form and then grow up gradually with increasing ageing time. η' phase forms after ageing for 4 h and η phase starts to occur after 24 h aging.

Key words: 7055 aluminum alloy; aging; precipitation, microstructure; property

1 Introduction

7055 aluminum alloy has low density, high strength, good fracture toughness and stress corrosion resistance, and it is an ideal light structure material for aerospace industry[1−3]. This kind of alloy is an aging-hardening Al-Zn-Mg-Cu alloy and heat treatment processing has a great effect on its microstructures and properties[4−7]. In order to obtain the combination of high strength, good fracture toughness and stress corrosion resistance, 7055-T77 temper has been developed[8−10]. T77 temper is a kind of triple-stage aging. The first-stage is peak aging, the second-stage is regression treatment, and the third-stage is re-aging following regression treatment. The results show that the temperature and time of re-aging is close to those during the peak aging of the first-stage. So optimization of the peak aging under single-aging condition of this alloy is very significant. In the present work, the relationship of mechanical, electrical properties with single-aging processing of 7055 aluminum alloy was studied. Based on this, microstructure development of different single-aging processing of the alloy was also studied.

2 Experimental

The composition of the studied alloy is listed in Table 1. The ingot with the diameter of 160 mm was obtained by semi-continuous casting, and then it was extruded into strips with 100 mm in width and 25 mm in thickness.

Table 1 Composition of studied alloy (mass fraction, %)

Zn	Mg	Cu	Zr	Fe	Si	Al
8.0	2.8	2.5	0.12	<0.2	<0.10	Bal.

Samples for tensile test were cut from the transverse direction of the strip and solution heat treated at 480 ℃ for 1 h, water quenched and aged at 110−120 ℃ for 0−48 h, respectively.

Hardness and electrical conductivity were measured. The tensile test rate was 2 mm/min. The XRD phase analysis was conducted on a D/max-2550/PC XRD instrument. TEM samples were mechanically thinned down to about 150 μm then electro-polished using a

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double jet with a 30% nitric acid and 70% methanol solution at 15 V and −20 ℃. TEM examinations were performed using a FEI Tecnai G2 20, operated at 200 kV.

3 Results

3.1 Effect of aging on mechanical properties and electrical conductivity of alloy

The hardness, electrical conductivity and tensile properties of the studied alloy at different aging treatments are shown in Figs.1 and 2. The results show that 7055 aluminum alloy has an obvious aging strengthening effect. At the early stage of aging, the hardness and strength of the alloy increase rapidly in 1 h, and approach to the peak value after aging for 4 h, then maintain at a high level for a long time. When aging temperature rises, the peak aging time will be shortened and the peak values of hardness and strength will be decreased. The suitable single-aging treatment of 7055 alloy is 480 ℃, 1 h solution treatment and water quenching, then aging at 120 ℃ for 24 h. Under this condition, tensile strength, yield strength, elongation and

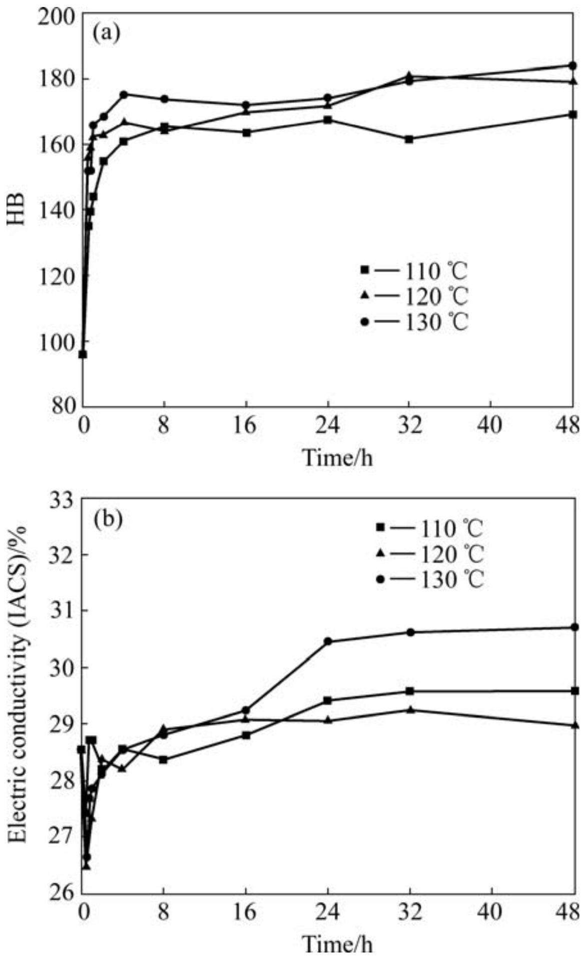

Fig.1 Effect of aging temperature on hardness (a) and electrical conductivity (b) of studied alloy

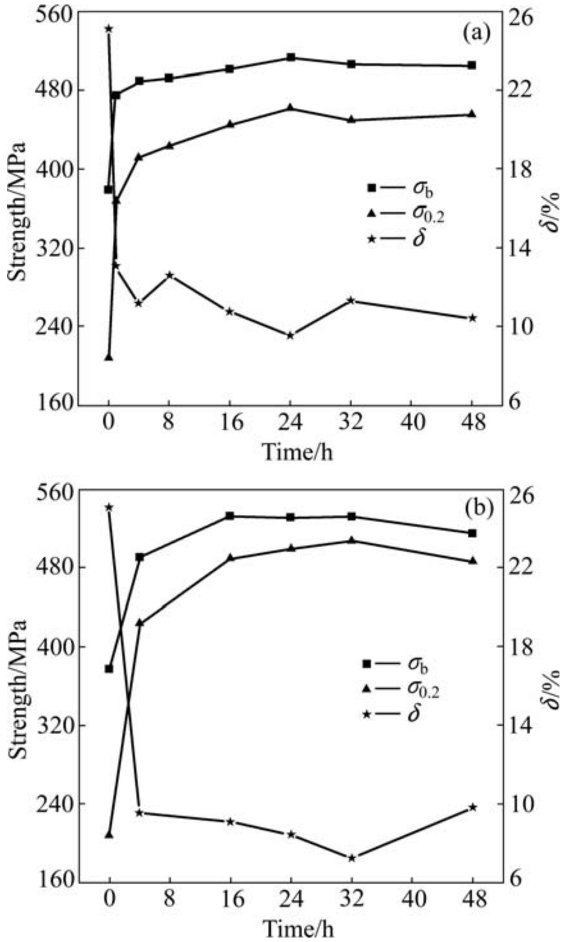

Fig.2 Mechanical properties of 7055 aluminum alloy at different ageing temperatures: (a) 120 ℃; (b) 130 ℃

electrical conductivity of the studied alloy are 513 MPa, 462 MPa, 9.5% and 29%(IACS), respectively. At the same time, the electrical conductivity of the alloy decreases at the beginning and then increases monotonously. The higher the aging temperature, the longer the aging time, and the higher the electrical conductivity of the alloy.

3.2 XRD phase analysis with different treatments

XRD patterns of 7055 aluminum alloy at solution treatment and typical aging treatment are shown in Fig.3. It can be seen that the microstructure of solution treated sample is basically a single Al base solution. During aging, η'($MgZn_2$) phase precipitates and the amount of the precipitates increases with the increase of aging time.

3.3 TEM microstructures observation

Fig.4 shows the bright field images in <011> projections of the alloys aged at 120 ℃ for 1, 4, 24, 32 and 48 h, respectively. The high-resolution electron micrograph and diffraction pattern of some typical aged alloys are shown in Fig.5.

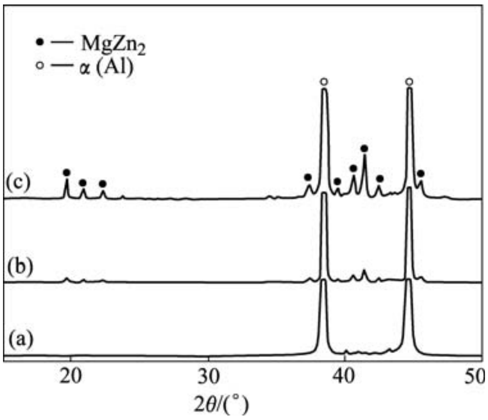

Fig.3 XRD patterns of 7055 aluminum alloy at different ageing treatments: (a) 480 ℃, 60 min, solution treatment; (b) 480 ℃, 60 min+120 ℃, 1 h; (c) 480 ℃, 60 min+120 ℃, 24 h

Figs.4 and 5 show that after aging at 120 ℃ for 1 h, besides spherical Al_3Zr dispersoid, many uniformly distributed dark particles within Al matrix are observed (Fig.4(a)). Some of particles appear round in the image with a diameter of 3−4 nm, but others appear slightly elongated. High resolution electron microscopy(HREM) reveals that at early-stage of 120 ℃ aging, GP zones are actually disc-shaped and their spherical morphology is caused by strain field that contributes to the diffraction contrast of these particles (Fig.5(a)). After the formation of GP zones, metastable η' phase starts to appear (Figs.5(b)−(c)).

After aging at 120 ℃ for 4 h, there is no significant difference in the size and morphology of GP zones as compared with those observed in Fig.4(a). However, from high resolution electron microscopy,

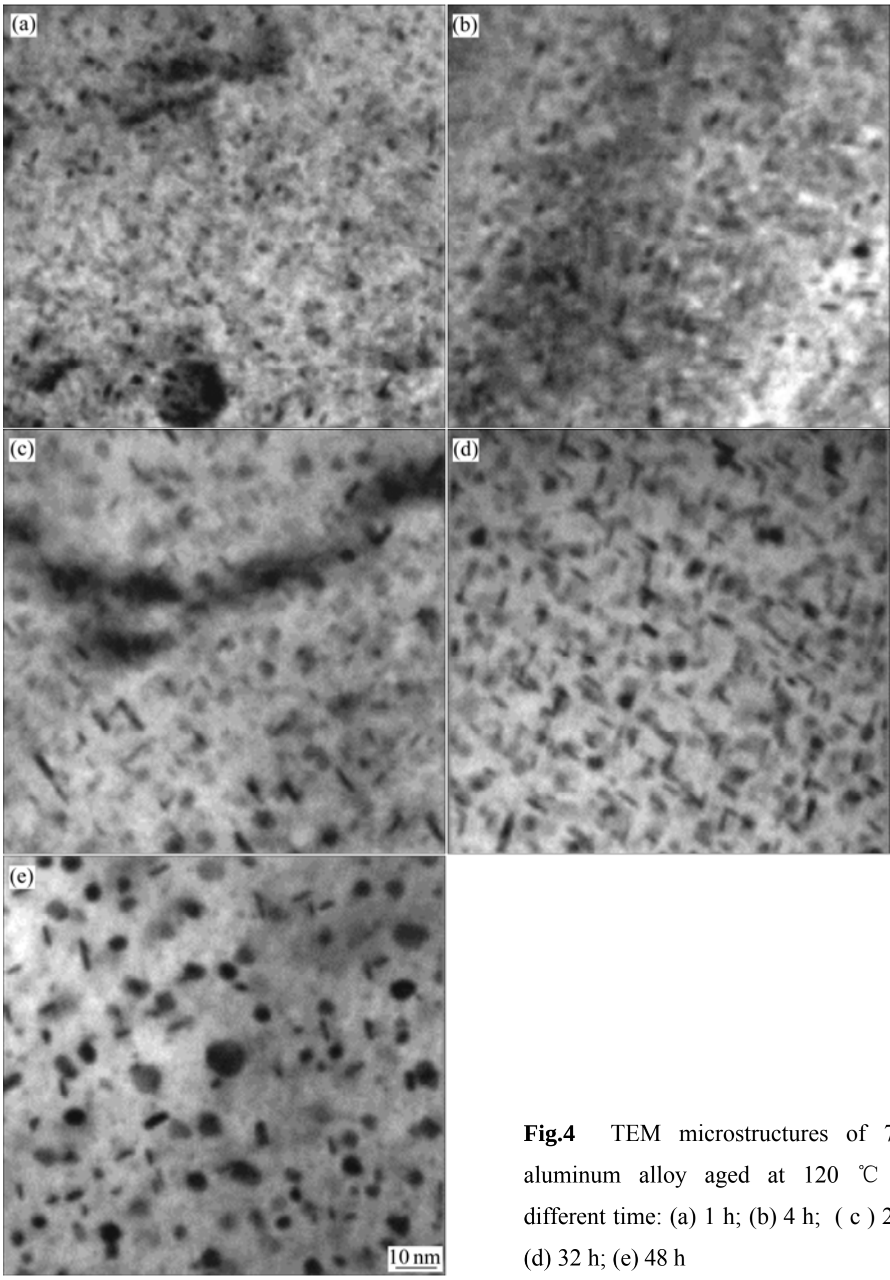

Fig.4 TEM microstructures of 7055 aluminum alloy aged at 120 ℃ for different time: (a) 1 h; (b) 4 h; (c) 24 h; (d) 32 h; (e) 48 h

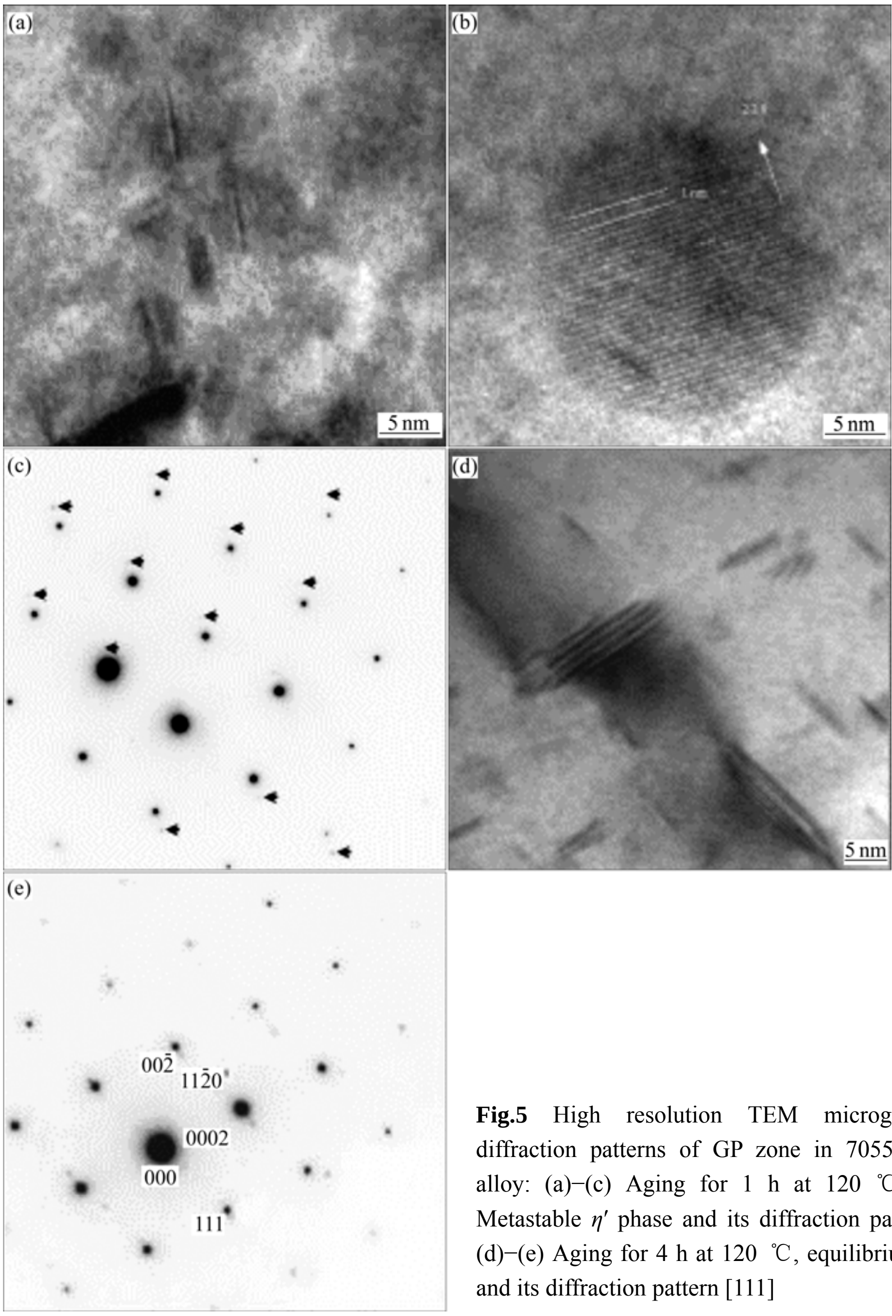

Fig.5 High resolution TEM micrographs and diffraction patterns of GP zone in 7055 aluminum alloy: (a)−(c) Aging for 1 h at 120 ℃; (b) −(c) Metastable η' phase and its diffraction pattern [110]; (d)−(e) Aging for 4 h at 120 ℃, equilibrium η phase and its diffraction pattern [111]

the strong η' diffraction feature in <011> diffraction pattern in Fig.5(e) indicates that metastable η' phase starts to form in the alloy. Fig.5(d) shows a high resolution electron micrograph of η' phase, Fig.5(e) shows its corresponding diffraction pattern with strong spots from Al matrix and weak spots from η' phase.

When the sample is aged at 120 ℃for 24 h, GP zone showing two kinds of morphology can be observed. One is elongated particles, the other is non-elongated particles (Fig.4(c)). With the further aging, more large η' phases and η phases are observed (Figs.4(d) and (e)). At the same time, it is noted that the density of GP zone becomes significantly lower as the size of GP zone increases.

4 Discussion

4.1 Effect of single aging on mechanical properties of 7055 aluminum alloy

During aging, supersaturated Al solid solution decomposes, precipitation occurs, and then the hardness and strength of the alloy increase. The total content of Zn, Mg and Cu in 7055 aluminum alloy is about 14%, the supersaturation degree of the matrix at solution treatment is very high and it is easier to decompose. So aging response of the alloy is also very quick, and only 1 h aging can approach the peak value aging (Figs.1(a) and 2(a)). The precipitating sequence of Al-Zn-Mg alloy is as follows[11−14]: α_{sss} (supersaturation solid solution)→GP zone → η'(substable state $MgZn_2$) → η (stable state $MgZn_2$). Adding of copper will promote the nucleation of the GP zones and η rather than change above-mentioned precipitation order. Fig.2 verifies this precipitating sequence. During aging, the kinetics of aging is controlled by the diffusion of the solute atoms. At the given aging temperature, the size and the quantity of the precipitates will increase with the increasing of the aging time. On the other hand, the precipitation kinetics will be greatly varied with aging temperature. The higher the aging temperature, the easier the solute atoms migration, and the shorter the peak value aging time (Figs.1(a) and 2(a)).

4.2 Effect of single aging on electrical conductivity of 7055 aluminum alloy

In the 7055 aluminum alloy, the phase composition consists of the Al matrix and η' ($MgZn_2$) precipitates. Under the solution treatment condition, the phase composition mainly consists of supersaturated Al matrix, and electron wave is greatly scattered by solutes, so electrical conductivity of the alloy is very low. At the early stage of aging, supersaturated Al matrix decomposes and GP zone precipitates. GP zone is coherent with the matrix, which leads to additional scattering, so the electrical conductivity of the alloy further decreases. With continuous aging, GP zones transform to η' ($MgZn_2$) and η($MgZn_2$), the supersaturation degree of the matrix greatly decreases and gradually approaches to pure Al. According to Mathiessen theory[15], the electrical resistivity of the alloy can be expressed as

$$\rho=\rho_0+\Delta\rho_s+\Delta\rho_p++\Delta\rho_v+\rho_d+\Delta\rho_g \tag{1}$$

where $\Delta\rho_s$ is the electrical resistance caused by the solid soluble atoms; $\Delta\rho_p$ is the resistance caused by the precipitated phase; $\Delta\rho_v$ is the resistance caused by the vacancy; $\Delta\rho_g$ and $\Delta\rho_d$ are the resistances caused by the grain boundaries and dislocations, respectively. Among them the greatest influence factor is $\Delta\rho_s$, followed by $\Delta\rho_p$, $\Delta\rho_g$, $\Delta\rho_v$ and $\Delta\rho_d$. The electron scattering caused by the soluted atoms distorting the aluminum matrix lattice is much greater than that caused by the precipitates. Therefore, during aging the conductivity of the alloy will rise. The higher the aging temperature, the longer the aging time. And the purer the matrix, the higher the conductivity of the alloy (Fig.1(b)).

5 Conclusions

1) 7055 aluminum alloy has very strong aging strengthening effect. The suitable solution-single aging processing of the alloy is solution treating at 480 ℃ for 1 h, water quenching, then aging at 120 ℃ for 24 h. Under these conditions, the tensile strength, yield strength, elongation and electrical conductivity are 513 MPa, 462 MPa, 9.5% and 29%(IACS), respectively.

2) During aging, the solid solution decomposes and GP zones precipitate at first, then grow up gradually with increasing of aging time. η' phase forms after aging at 120 ℃ for 4 h, and η phase starts to occur after 24 h aging.

3) At the early stage of aging, supersaturated Al matrix decomposes, GP zone precipitates, electron scattering increases, and electrical conductivity decreases. With continuous aging, GP zones transform to η'($MgZn_2$) phase, the solubility of the matrix declines and the electrical conductivity rises. The higher the aging temperature, the longer the aging time, and the higher the electrical conductivity of the alloy.

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